EARLY VALIDATION OF OPERATIONAL SAR WIND RETRIEVALS FROM SENTINEL-1A

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1. INTRODUCTION

The computation of wind speeds at high (< 1 km) resolution from spaceborne synthetic aperture radar (SAR) is a mature geophysical application. A number of researchers, a modest sample of which are cited [1, 2, 3, 4, 5, 6, 7], have described the geophysical relationship between normalized radar cross section (NRCS) and ocean surface wind speed, and how this relationship can be exploited to infer wind speeds. In May 2013, NOAA began the operational production of SAR-derived wind speed maps using Canadian Radarsat-2 imagery purchased by the U.S. National Ice Center. Monaldo et al. [8] chronicle the history of the first observation of ocean wind features from the Seasat SAR and its evolution to an operational product.

Since NOAA operations began, approximately 7200 Radarsat-2 SAR images have converted to 500-m resolution wind speed images. Results are available 5 hours from acquisition. The wind speed processing itself requires about 5 minutes so most of the latency involves data downlink and processing raw signal data into NRCS SAR images.

On April 3, 2013, ESA launched Sentinel-1A, the first in a pair of SAR identical satellites. This system has completed its on-orbit commissioning phase and will begin routine operations in June 2015. These data are free and open and available to registered users. In addition, international partners will have quicker and more robust access via a separate link. We anticipate that NOAA will begin preliminary operational wind processing with Sentinel-1A data as an international partner in 2015.

A key step for transition to operations is validating performance in wind speed retrieval. The NOAA requirements for operations are a standard deviation of 2 m/s or better for wind speeds less than 15 m/s. Sentinel-1A is still undergoing calibration, but data have been released that include a preliminary calibration. Here we show that even with this preliminary calibration, Sentinel-1A SAR imagery can be used to produce wind speed images that meet NOAA requirements for operation wind retrieval. Results will be more definitive after Sentinel-1A calibration is completed and certified by the mission team and more validation data accumulated.

2. COMPARISONS AND CONCLUSIONS

Unfortunately, it is difficult to find a large number of spatially-diverse fiducial wind speed measurements against which to compare SAR and other remote sensing measurements. Instead, we must use a variety of independent wind speed estimates to arrive at a consensus on the validation of SAR-derived marine wind speeds. We use here scatterometers and numerical forecast models to compare against Sentinel-1A wind speed retrievals. Marine buoy measurements, while important, are too few in number in the data we have acquired to arrive at statistically reliable comparisons.

Scatterometers produce wind measurements at much lower resolution than typical SARs. The resolution of scatterometer wind speed estimates vary from 12 to 25 km¿ SARs typically operate 10 to 100 resolution. For our purposes, we average SAR imagery to 500 m before wind speed retrieval Hence, SAR measurements must be averaged to the same lower spatial resolution for appropriate comparison against scatterometer measurements. To minimize the effects of temporal separation, the measurement times between the two instruments must be small (< 2 hours). Model winds are available at all locations, also at lower resolution (e.g. 0.5° longitude-latitude for Global Forecast System (GFS) model winds) and are available every 6 hours with predictions provided every 3 hours. Buoys provide the best temporally resolved wind measurements (10 min) but have the poorest spatial sampling (a single location). For our comparisons here, we did not use buoys. Most of the data were acquired at high latitudes, were buoy coverage is limited.

Validation of Sentinel-1A wind retrievals was done using both numerical model winds and the ASCAT scatterometers. Since a large fraction of the Sentinel-1A imagery are at high latitude, a large number of scatterometer comparisons within a few hours could be obtained. For the period 2014 Dec 01 to 2015 Jan 01, comparisons were made between spatially coincident ASCAT scatterometer wind retrievals separated from Sentinel-1A wind retrievals by less than two

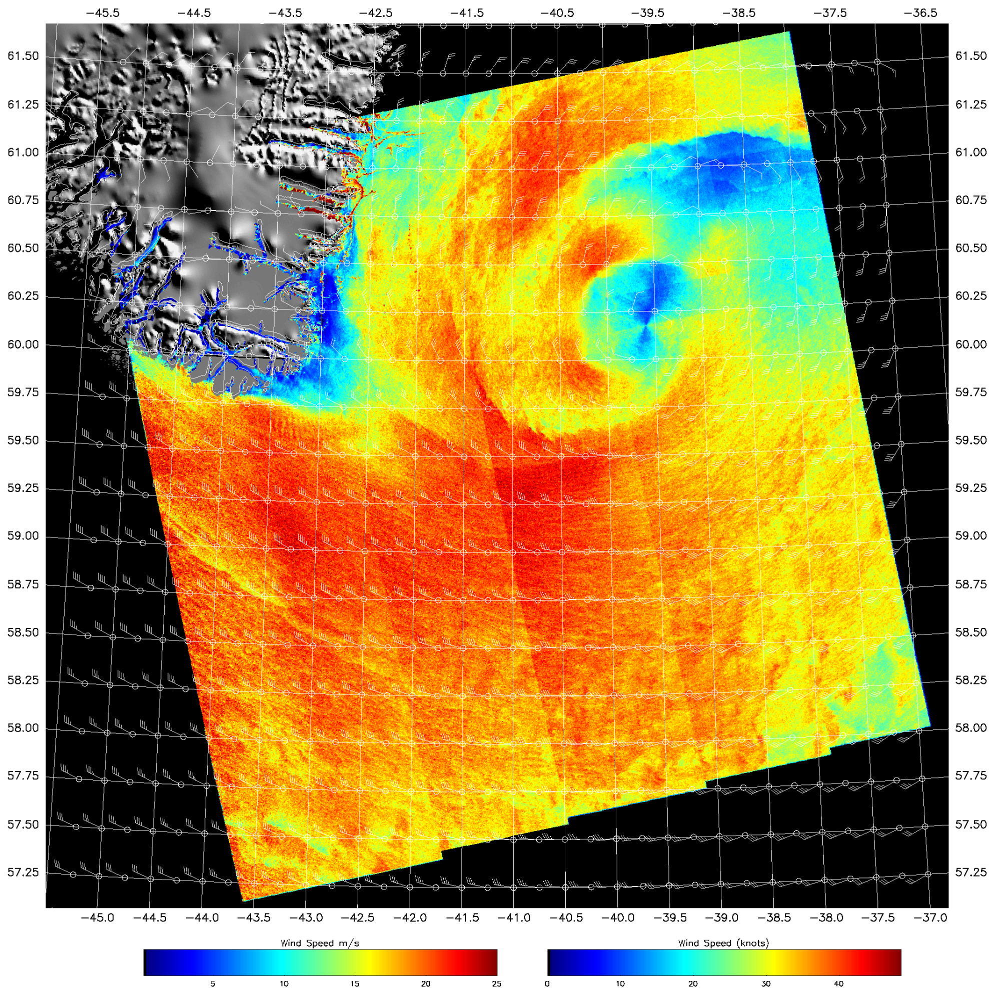

Fig. 1. Sample Sentinel-1A wind speed retrieval off the coast of Greenland for 2014 Dec 31 20:19:38 showing a low pressure system. The wind speed color scale extends from 0 to 25 m/s.

hours. The ASCAT files also include the wind speed estimates from the European Center for Medium-Range Weather Forecasting (ECMWF) model. The SAR winds output files also include the GFS model winds. Hence, for each matching Sentinel-1A and ASCAT comparison, a Sentinel-1A versus ECMWF model and a Sentinel-1A versus GFS model comparison were also available. SAR winds were averaged into $25~\mathrm{km} \times 25~\mathrm{km}$ areas matching the scatterometer measurement. Ocean areas flagged as ice by the ASCAT ice flag were excluded from the comparisons. A total of 37,221 comparison triplets were available for the examined time period. The CMOD4 model function [9] relating the wind vector to NRCS with the Thompson polarization ratio ($\alpha = 0.6$) [10] was used for the wind speed retrieval.

Table 1 demonstrates close agreement between the Sentinel-1A SAR wind speed measurements (with preliminary calibration) and the other estimates. The standard deviations between Sentinel-1A SAR and ASCAT retrievals were less than 2 m/s. The standard deviation of the SAR winds with respect to both the GFS and ECMWF are slightly greater than 2 m/s over the entire 0–25m/s range measured. For wind speeds less than 15 m/s, the standard deviations drop. Even against the models, the standard deviations are close to 2 m/s Certainly some part of the difference is not associated with SAR retrievals, but with the models and the temporal separation between comparisons. It is interesting to note that the minimum standard deviation in the wind speed estimates exists for the Sentinel-1A SAR and ASCAT comparisons. This suggests that there is some wind speed variations captured by both ASCAT and Sentinel-1A, not found in the model estimates. All the publicly available geophysical model functions (relating wind speed and direction to NRCS) have not yet been tested to determine if one yields smaller residual differences. In addition, the ASCAT ice flag may not be totally effective in eliminating ice contaminated SAR retrievals.

Figure 2 shows how well Sentinel-1A wind speed mea-

Table 1. Comparison between Sentinel-1A wind retrievals and ASCAT, GFS, and ECMWF estimates.

	Mean Difference	Standard Deviation	Number
All wind speeds			
ASCAT	−0.67 m/s	1.73 m/s	37221
ECMWF	0.24 m/s	2.20 m/s	37221
GFS	0.35 m/s	2.26 m/s	37221
Wind speeds < 15 m/s			
ASCAT	−0.89 m/s	1.49 m/s	32904
ECMWF	0.00 m/s	2.01 m/s	32904
GFS	−0.45 m/s	2.05 m/s	32904

surements agree the independent estimates as a function of wind speed. The black, red, and blue lines represent comparisons with ASCAT, GFS, and ECMWF, respectively. The perfect agreement line is gray. The error bars represent the 1-standard deviations in the comparisons for each 1-m/s wind speed bin. The right side of the figure is a histogram of SAR wind speeds, which peaks at 5 m/s. The consensus of the comparison of Sentinel-1A wind speeds and other estimates is that they show good agreement in the wind speed regime sample. There is a slight high bias in Sentinel-1A retrievals at wind speeds greater than 15 m/s. As we gather more data over 2015 and Sentinel-1A's calibration is certified, we expect to reach more definitive conclusions.

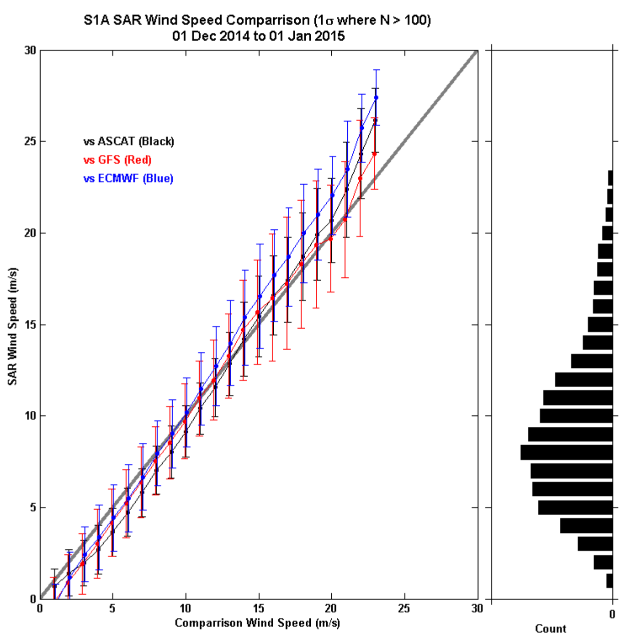

Fig. 2. Binned comparisons between Sentinel-1A wind speeds and ASCAT (black), GFS (red), and ECMWF (blue). The histogram on the right shows the distribution of wind speeds sampled.

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